EEU44C04 / CS4031 / CS7NS3 / EEP55C27
Next Generation Networks

Wireless local area networks: HetNet and small cell deployments, mmWave

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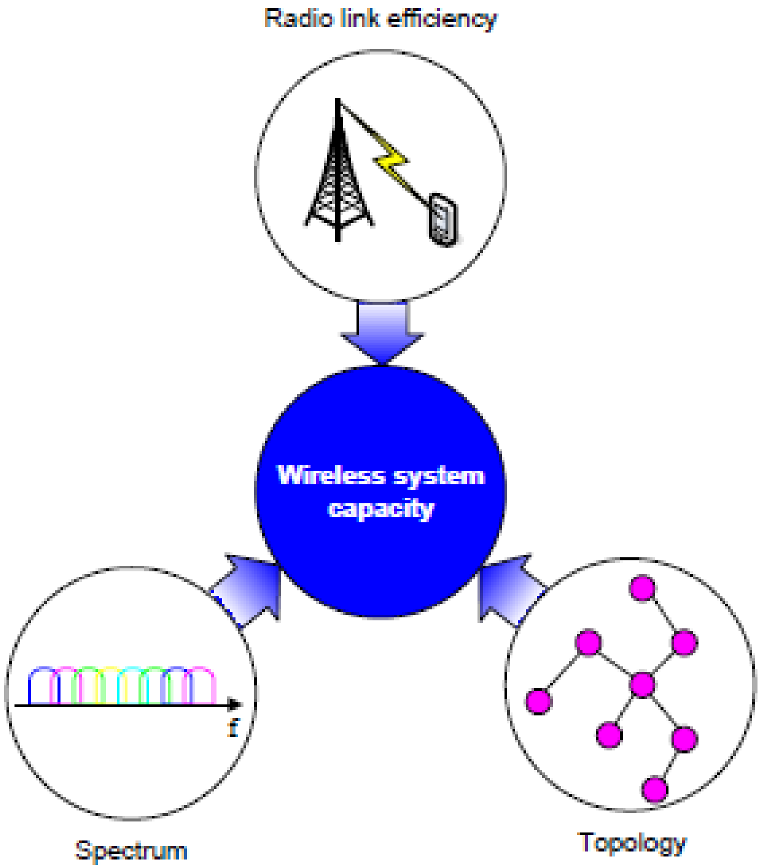
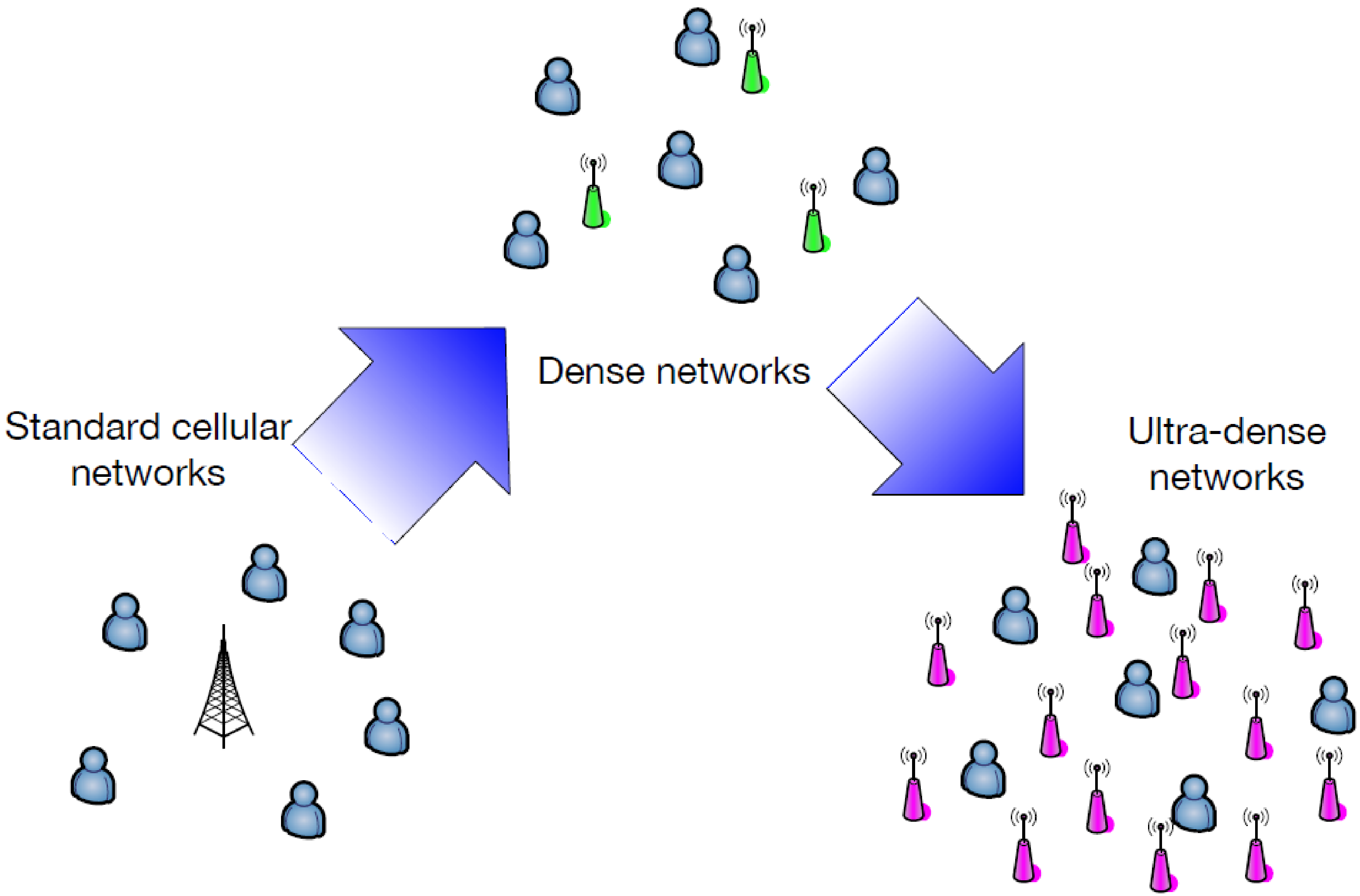
Improving the Capacity

How do we cope with the demand for higher capacity?

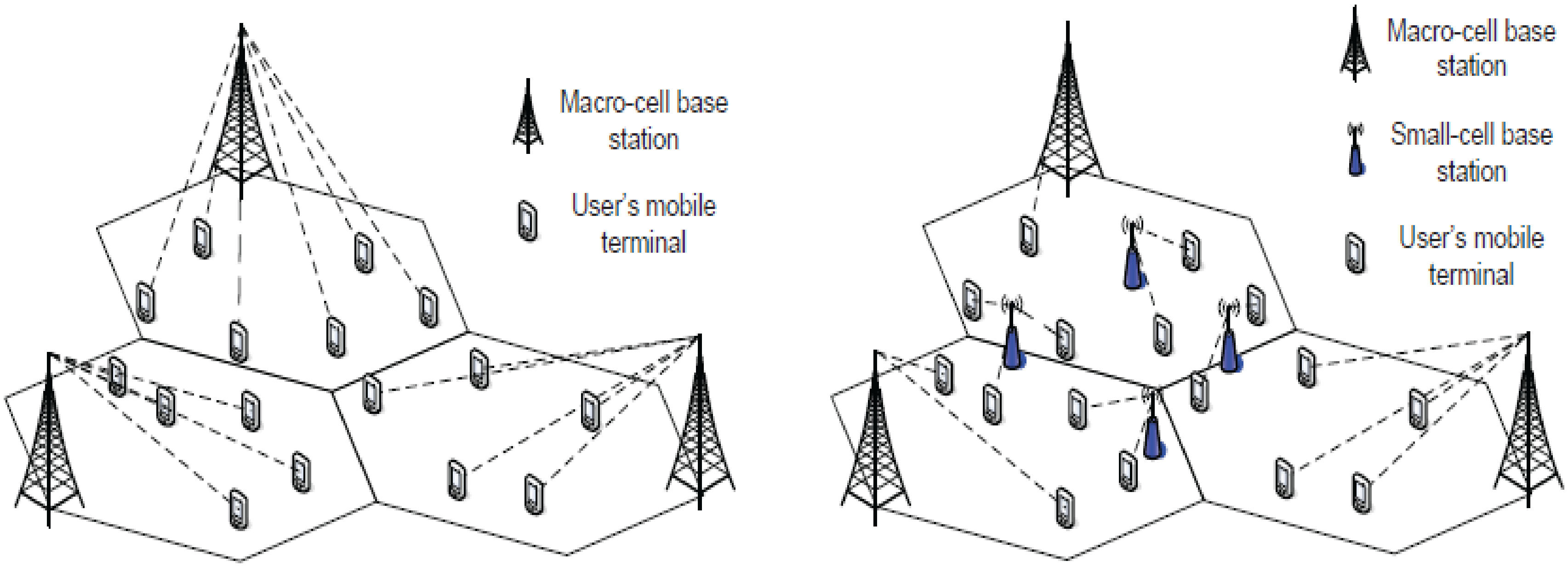
1. Radio link efficiency: more bps over the same link.
2. Spectrum: getting more spectrum.
3. **Topology**: more nodes in the wireless infrastructure.



Cell Densification

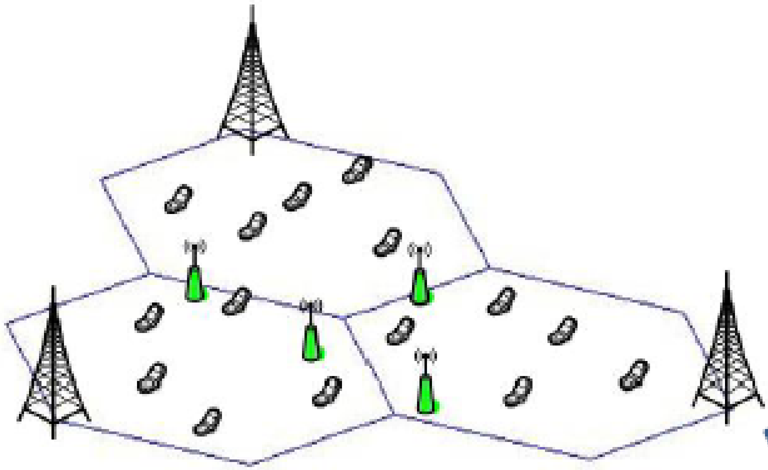


HomNet vs HetNet



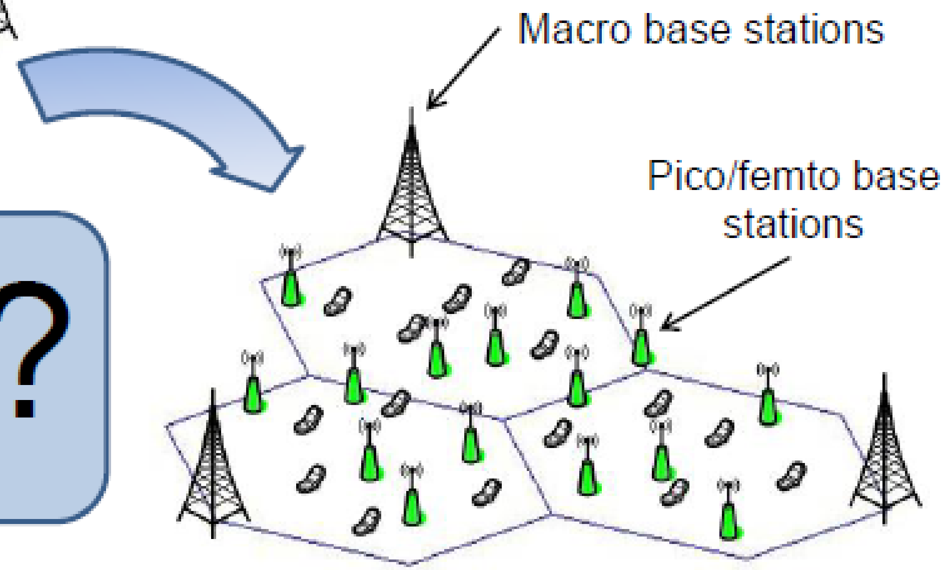
(a) Homogeneous Network (b) Heterogeneous network

Worth It?



Heterogeneous networks:

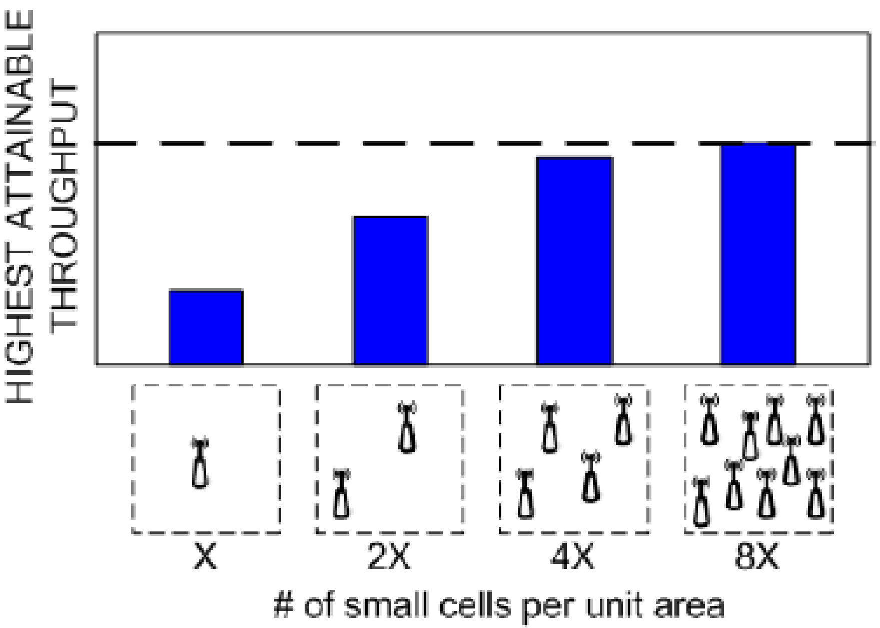
- Improved coverage for cell-edge users
- Higher throughput



MORE NODES = HIGHER THROUGHPUT ?

Sometimes Not Worth It!

Area Spectral Efficiency upper bound



THROUGHPUT IS UPPER-BOUNDED [1]!!!

Under given conditions:

- Femtocells scenario
- Random channel access
- Limited and fixed bandwidth
- Limited and fixed area

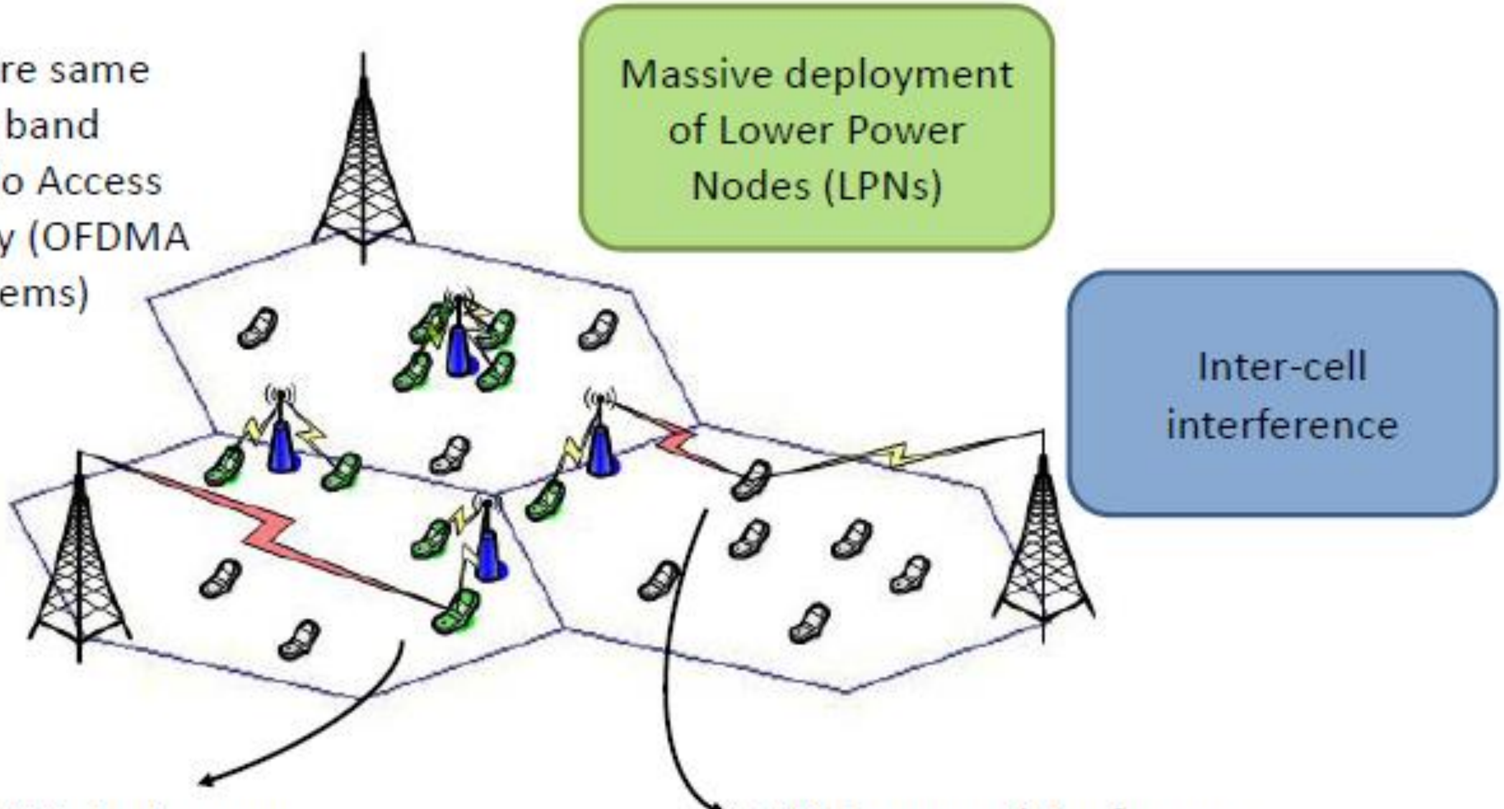
$$\text{Area Spectral Efficiency} = \frac{\text{Throughput}}{\text{Area} \cdot \text{Bandwidth}}$$

Effect of inter-cell interference

[1] Chandrasekhar, V. & Andrews, J. G., *Spectrum Allocation in Tiered Cellular Networks, IEEE Transaction on Communications*, 2009, 57, 3059 - 3068

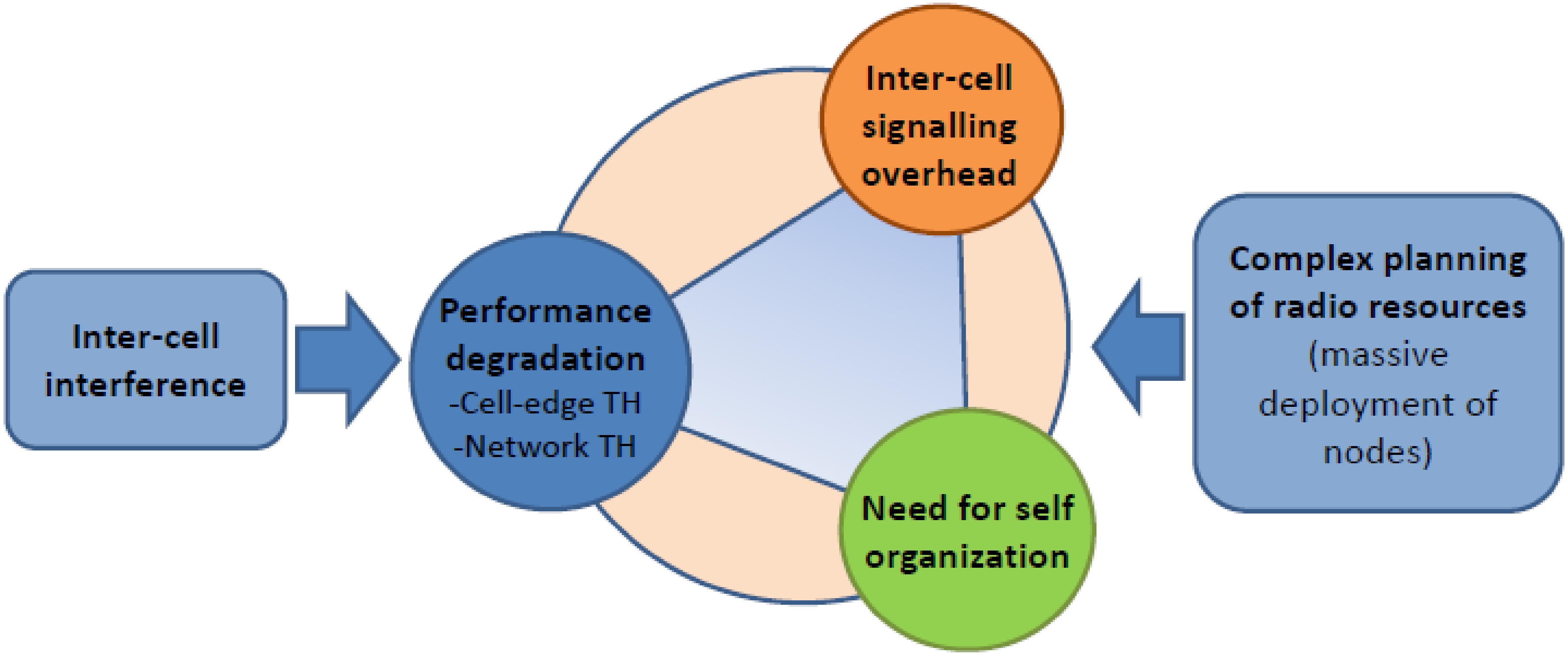
Interference in HetNet

- Nodes share same frequency band
- Same Radio Access Technology (OFDMA based systems)



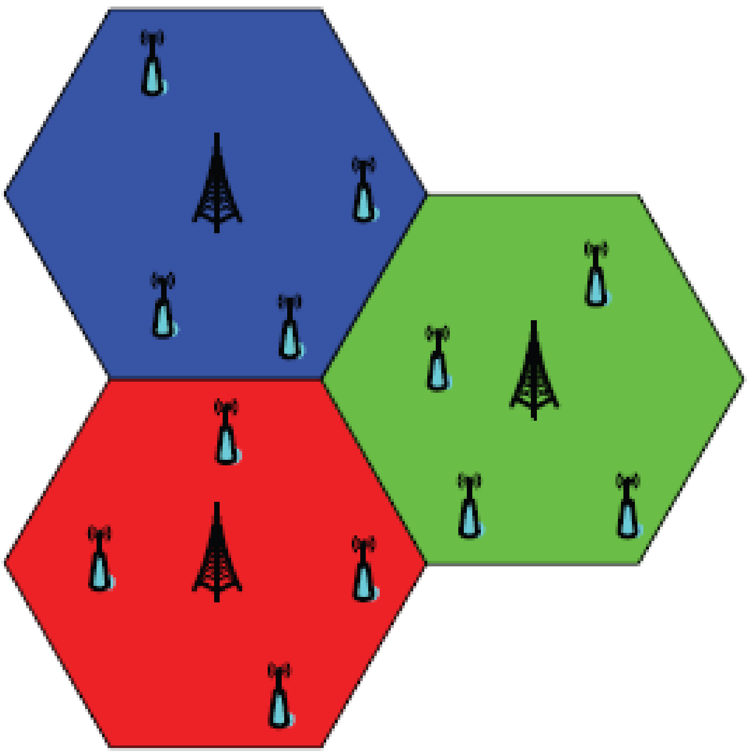
ACRONYMS
LPN = Low Power Node

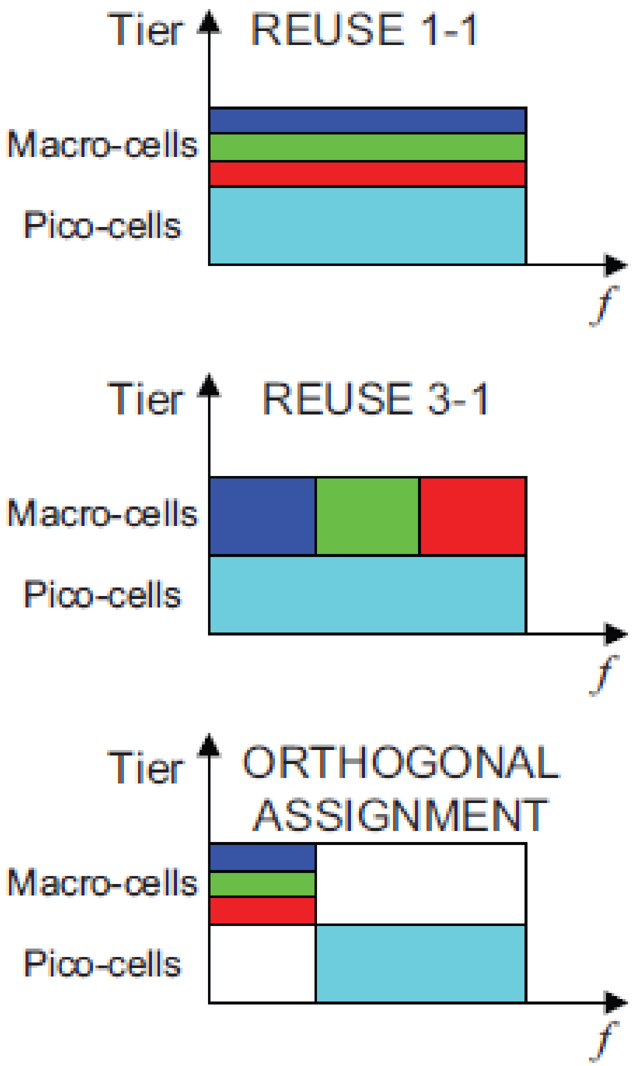
HetNet - Issues



ACRONYMS
TH = throughput

Fixed Spectrum Allocation for HetNet

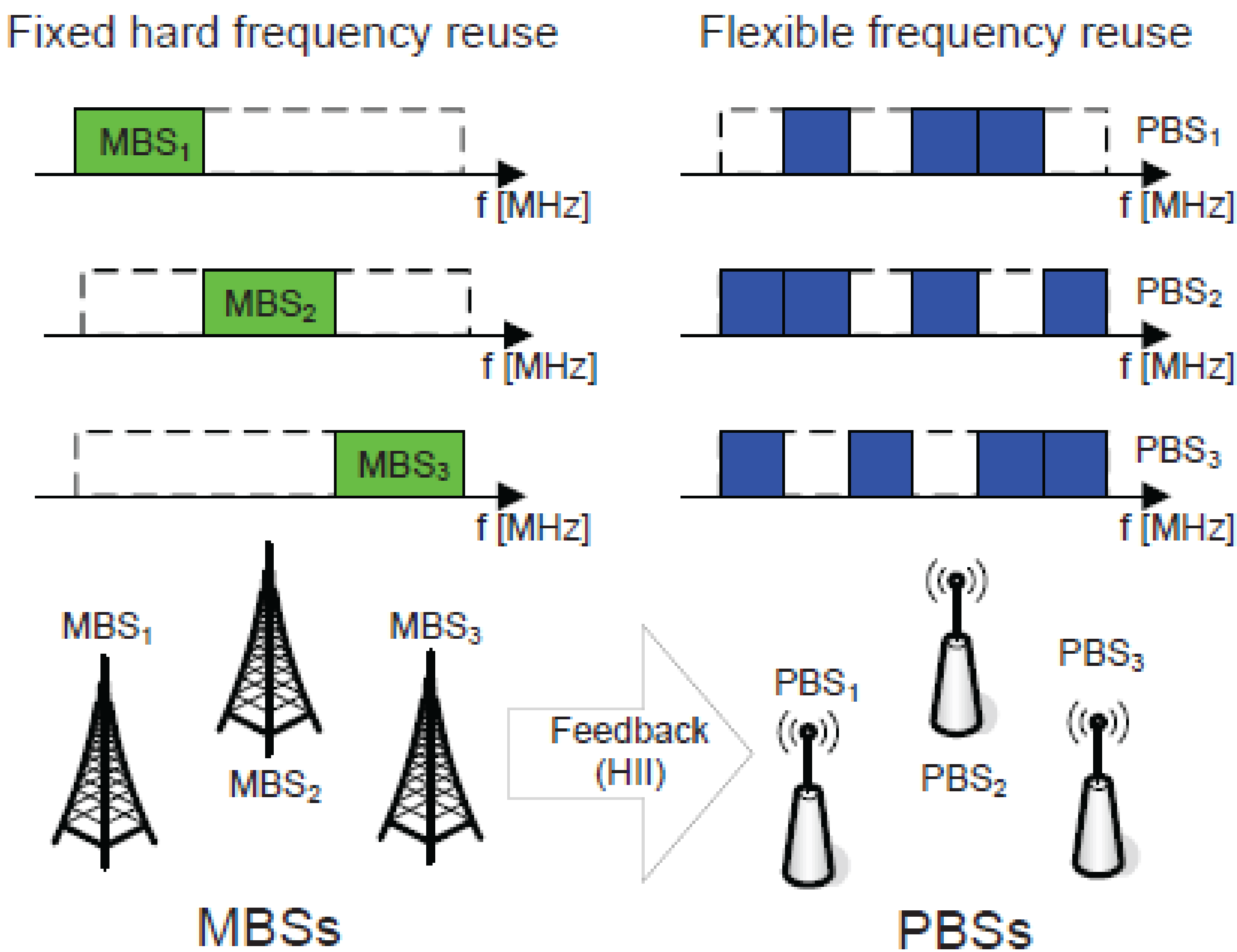




Fixed vs Flexible Reuse

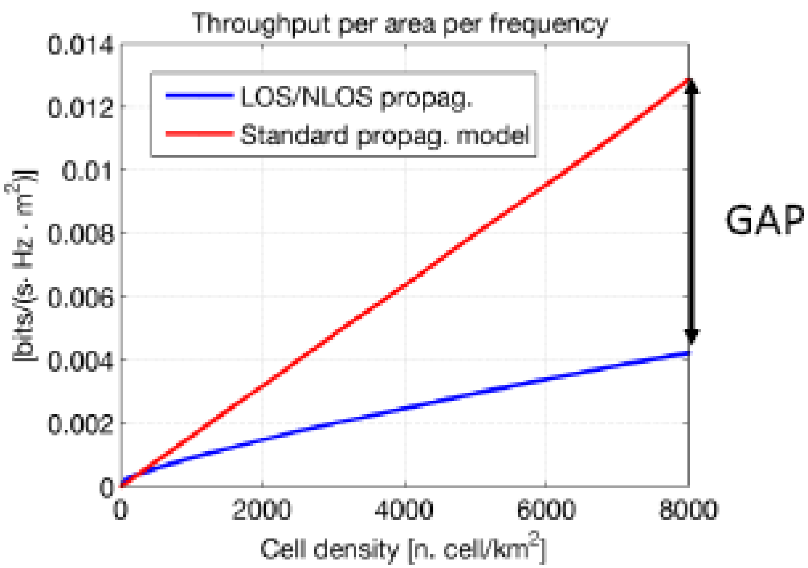
MBS =
Macro
Base Station

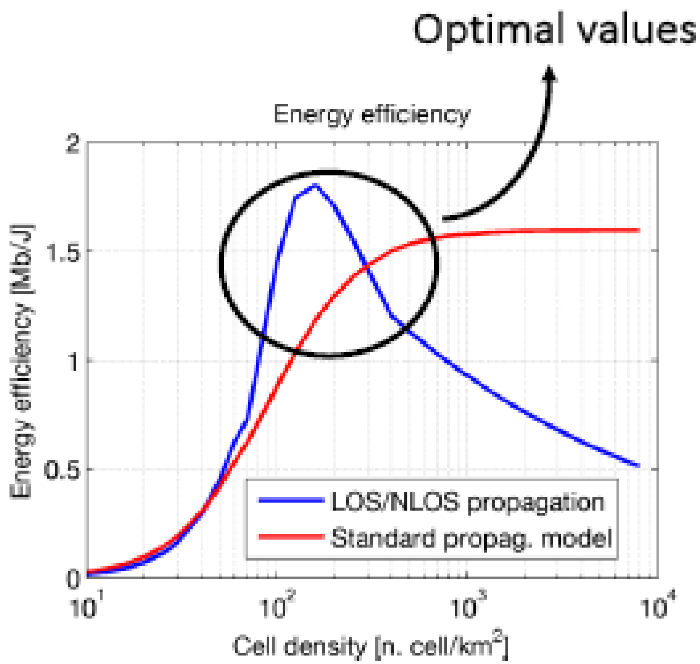
PBS =
Pico
Base Station
(a.k.a. Small
Cell or Low
Power Node)



HII = High Interference Indicator

The Propagation Model matters!





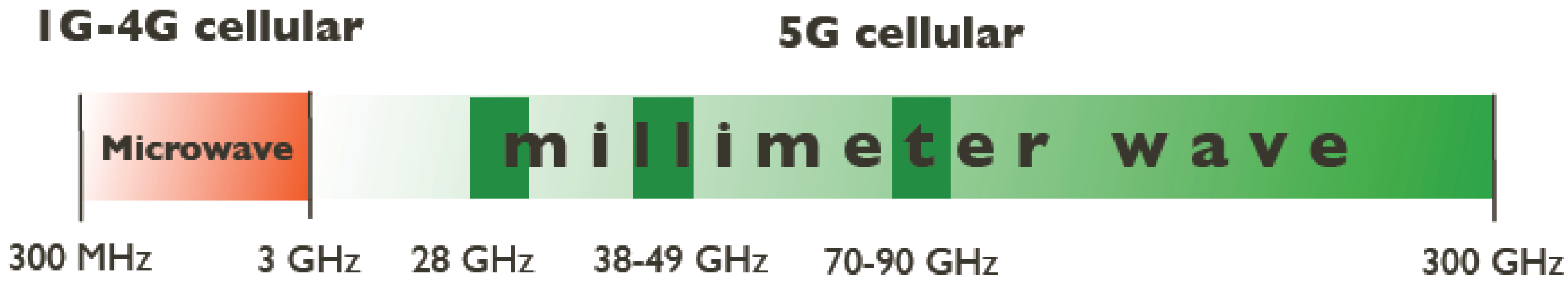
- Standard systems models hide issues of dense cells.
- A region of optimal BS densities emerges

LOS = Line of Sight
NLOS = Non Line of Sight

MU = Multi User
PAN = Personal Area Network
VANET = Vehicular Ad-hoc Network

mmWave

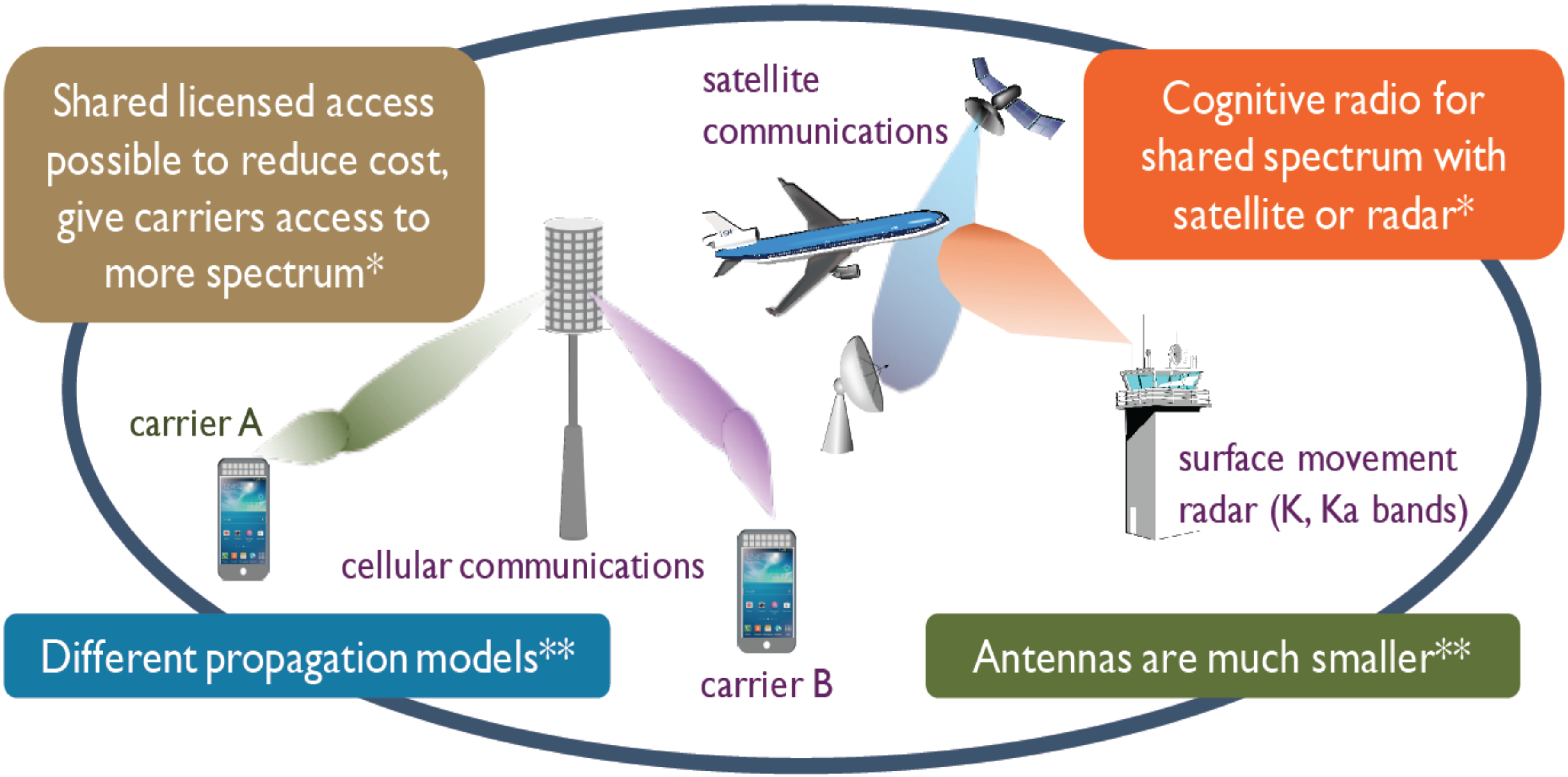
E-band = 71-76 and 81-86 GHz



- Cellular systems live with a little microwave spectrum
  - 600MHz total (best case) in the US
  - Spectrum efficiency is king (MIMO, MU MIMO, HetNets)
- Huge amount of spectrum available in mmWave bands
  - 29GHz **possibly** available in 23GHz, LMDS, 38, 40, 46, 47, 49, and E-band
  - mmWave already used in LAN, PAN, and VANET
  - mmWave links are used for backhaul in cellular networks

LMDS = Local Multi-point Distribution Service

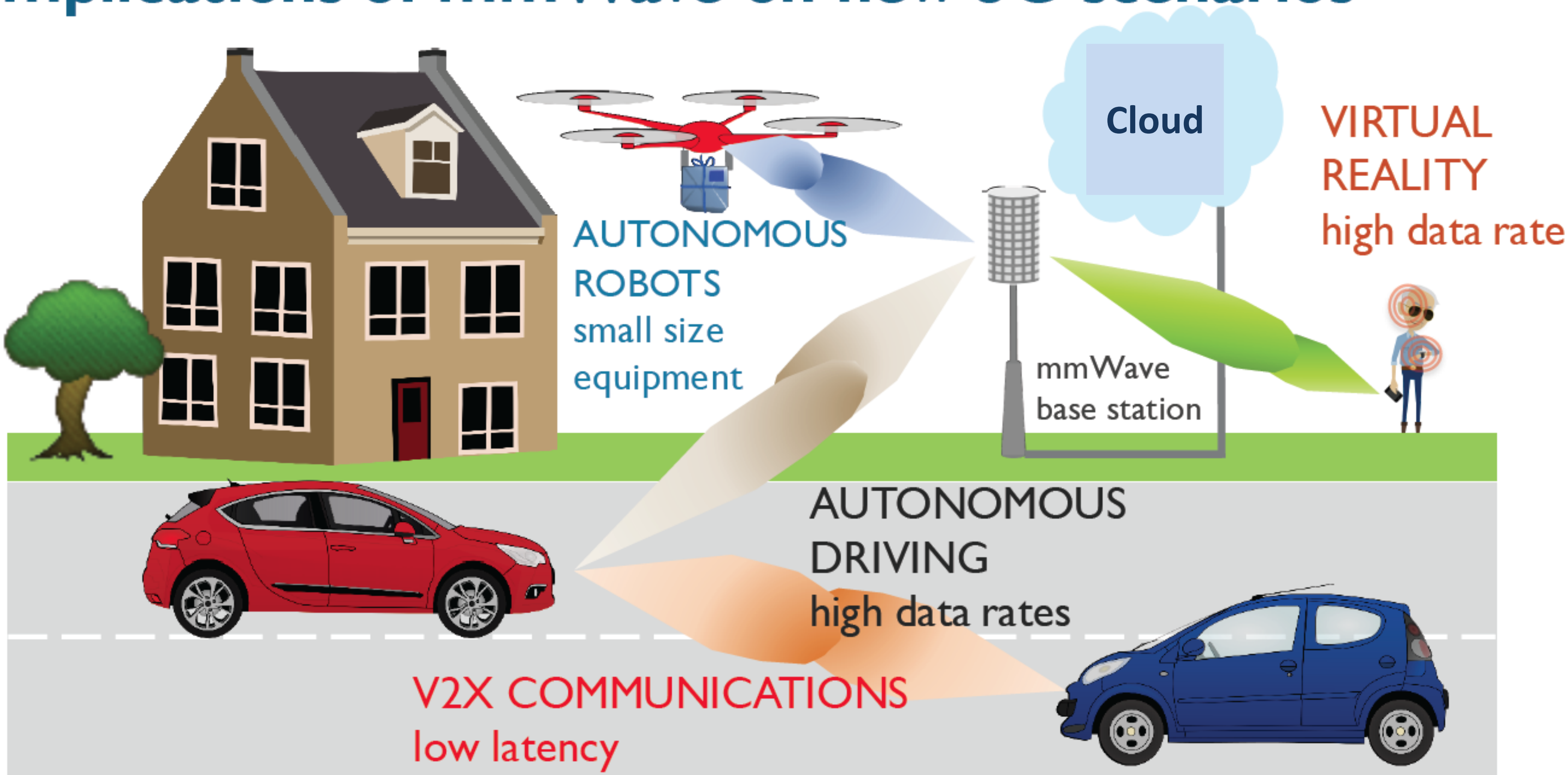
Implications of millimeter wave spectrum



K-band = 18-27 GHz
Ka-band = 26.5–40 GHz

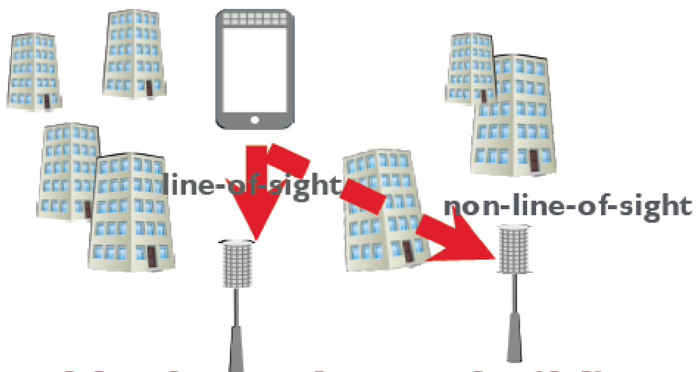
V2X = Vehicle-to-everything

Implications of mmWave on new 5G scenarios

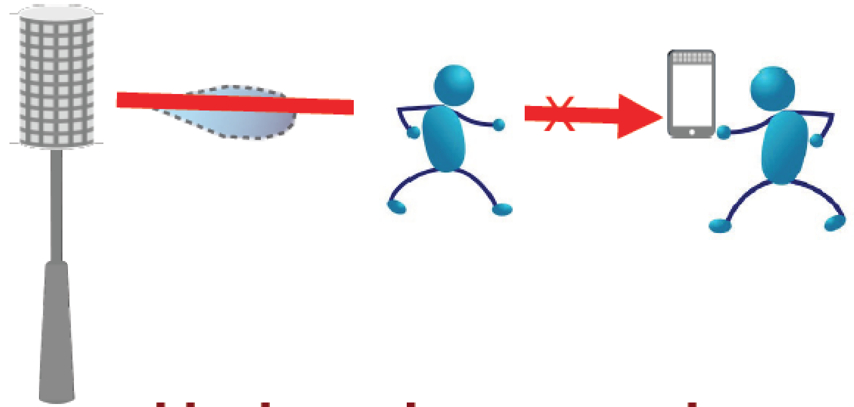


MmWave high data rates are required in different 5G scenarios

Blockage is a major channel impairment

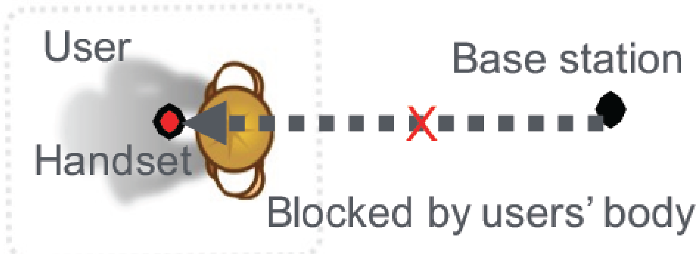


blockage due to buildings



blockage due to people

hand blocking

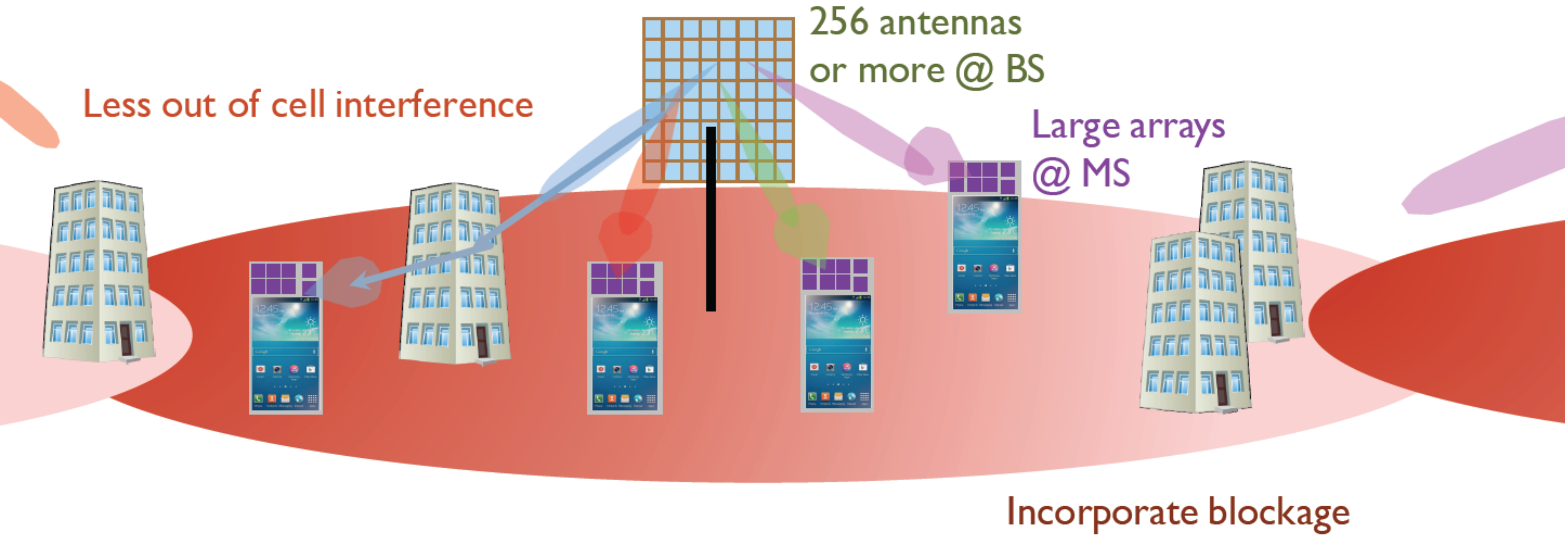


self-body blocking

Need models for blockage & system analysis including blockage

BS = Base Station
MS = Mobile Station (a.k.a. User Equipment (UE))

Multiuser or massive MIMO at mmWave



Large arrays are a natural application of massive MIMO techniques

mmWave – Key Points

- Observations
  - Coverage may be acceptable with the right system configuration
  - Strong candidate for higher per-link data rates
  - Hardware can leverage insights from 60GHz LAN and PAN
  - Highly directional antennas may radically change system design
  - Supporting mobility may be a challenge
- **Outlook**
  - **Part of 5G as access to new spectrum becomes available**
  - **mmWave to co-exist with microwave cellular systems**
  - Will remain useful for niche applications like backhaul

Acknowledgements

- Dr Carlo Galiotto, TCD
- R.W. Heath, “What is the Role of MIMO in Future Cellular Networks: Massive? Coordinated? mmWave?”
- R.W. Heath, "Millimeter Wave for 5G Features and implications"

Which one among the following statements characterizes Ultra Dense Networks?

- ❑ There are more UEs than BSs
- ❑ There are more BSs than UEs
- ❑ There are approximately as many BSs as UEs

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What do we mean by reuse 3-1 in the context of HetNet?

- ❑ Macro BSs use 1/3 of the bandwidth and Pico BSs use all the bandwidth
- ❑ Macro BSs and Pico BSs use all the bandwidth
- ❑ Pico BSs use 1/3 of the bandwidth and Macro BSs use all the bandwidth

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We are given the following system components:

- SISO and MIMO systems. MIMO is 2x2 spatial multiplexing
- modulations of QPSK, 16-QAM, 64-QAM
- channel coding rates of 3/4, 1/2 and 1

With the available components, design three possible systems capable of providing a spectral efficiency of 6 bps/Hz, assuming S=I+N.

$$C = m \cdot B \cdot \log_2[1+S/(I+N)] = m \cdot B \rightarrow C/B = m$$

where m is the gain from using SISO/MIMO, modulation, and channel coding.

- SISO + 64-QAM + coding rate of 1

→1 spatial stream x 6 bits/symbol x R_c = 1 → 6 bps/Hz

- MIMO + 16-QAM + coding rate of 3/4

→2 spatial streams x 4 bits/symbol x R_c = 3/4 → 6 bps/Hz

- MIMO + 64-QAM + coding rate of 1/2

→2 spatial streams x 6 bits/symbol x R_c = 1/2 → 6 bps/Hz

The rank of a matrix can be defined as the number of independent columns. We can then calculate for a MIMO channel the corresponding rank. In case of:

- higher rank, experience proves it is better to go for MIMO spatial multiplexing (providing high data rate);
- lower rank, it is better to go for spatial diversity (high reliability).

Given the following MIMO channel matrices, which of the two is more suitable to achieve high data rate, and which one to achieve high reliability?

$$H_1 = \begin{bmatrix} 1 & 1 & -1 \\ 2 & 1 & 0 \\ 3 & 0 & 0 \end{bmatrix}, \quad H_2 = \begin{bmatrix} 0.5 & -1 & 1 \\ 1 & -2 & 2 \\ 1.5 & -3 & 3 \end{bmatrix}$$

H_1 has three independent columns, thus rank = 3 (no column can be obtained out of other columns' combinations).

In H_2, the second and third column can be obtained from the first one, multiplying by -2 and by 2, respectively, thus rank = 1.

H_1 is therefore more suitable to achieve higher data rate and H_2 to achieve higher reliability.

(a) Suppose we have a CDMA system and that a 0 is transmitted as a positive pulse +*L* and 1 is transmitted as a negative pulse - *L*. A certain station *A* is assigned the code 101111 and another station *B* can choose among the codes 101110, 010101, and 000101 respectively. Which code should *B* use and why?

[13 marks]

(b) Now suppose that simultaneously *A* wants to send a 1 and *B* wants to send a 0. What is decoded at the receiver for *A* and *B* transmissions? Outline in detail the decoding procedure.

[12 marks]

(a)

One verifies which of the three codes available at the second station is orthogonal with the code assigned to the first station, and this is the right code to use, as codes used by CDMA have to be orthogonal, in order to be able to separate the users in the code domain.

At the first station, 101111 is mapped into (-1,+1,-1,-1,-1,-1).
At the second station, 101110 is mapped into (-1,+1,-1,-1,-1,+1), 010101 into (+1,-1,+1,-1,+1,-1), and 000101 into (+1,+1,+1,-1,+1,-1).

By doing the dot products, we discover that:

$$\langle(-1,+1,-1,-1,-1,-1), (-1,+1,-1,-1,-1,+1)\rangle = +1+1+1+1+1-1 = 4 \neq 0$$
$$\langle(-1,+1,-1,-1,-1,-1), (+1,-1,+1,-1,+1,-1)\rangle = -1-1-1+1-1+1 = -2 \neq 0$$
$$\langle(-1,+1,-1,-1,-1,-1), (+1,+1,+1,-1,+1,-1)\rangle = -1+1-1+1-1+1 = 0$$

Therefore, 000101 is the only orthogonal code with respect to 101111, among those available at the second station.

(b)

A transmits -L x (-1,+1,-1,-1,-1,-1) = (+L,-L,+L,+L,+L,+L)
B transmits +L x (+1,+1,+1,-1,+1,-1) = (+L,+L,+L,-L,+L,-L)

Receiver gets the combined signal (+2L,0,+2L,0,+2L,0)

To decode A's bit, one takes the dot product of received signal and A's code:
<(+2L,0,+2L,0,+2L,0),(-1,+1,-1,-1,-1,-1))> = -2L+0-2L+0-2L+0 = -6L < 0, so a 1 was transmitted.

Same for B's bit:
<(+2L,0,+2L,0,+2L,0), (+1,+1,+1,-1,+1,-1)> = +2L+0+2L+0+2L+0 = 6L > 0, so a 0 was transmitted.